Investigation of Disturbance Magnetic Fields from Satellite Data Due to Magnetospheric/Ionospheric Currents and Waves

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LONG TERM GOALS

To understand the basic physics of magnetospheric and ionospheric currents and waves for the purpose of developing predictive models of magnetospheric dynamics. This requires characterizing the magnetic signatures of currrents and waves detected by spaceborne magnetometers at low Earth orbit and higher altitudes.

OBJECTIVES

- To characterize the relationship of magnetic auroral fluctuations with large scale field aligned currents and particle signatures. Such fluctuations have been shown to be ubiquitous in the auroral zones and may provide a simple techique for truly real time monitoring of the state of the auroral oval because analysis of the fluctuations does not depend on detrending procedures typically required for processing vector data.

- To understand the dynamics of large scale current systems during geomagnetic storms. During storms the auroral oval expands equatorward of the vast majority of ground observing stations and radars so that the only way to follow the dynamics of the currents through the course of a storm is via space borne instrumentation.

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- To understand the generation and propagation of magnetic disturbances and waves through the magnetosphere.

- To develop novel micro-miniature techniques for measuring magnetic fields to allow broader application of magnetic field measurements in space applications.

- To characterize low latitude magnetic perturbations associated with sudden comencemcents, substorms, and equatorial current systems.

APPROACH

- We used Freja and UARS magnetic field data to compare the fluctuation levels and the large scale field aligned current signatures to test the reliability of fluctuations to locate the auroral oval based on extrapolation of the statistical pattern of field aligned currents from one satellite to the location sensed by the other.

- We used UARS magnetic field data to study all of the storms during the UARS epoch. We have also acquired the recent DMSP magnetic field data, F12-F14, to perform correlative studies of magnetic field signatures with the SuperDARN radars, AMIE results, and Polar UVI and PIXIE images. To perform these comparisons we developed a modeling tool that allows us to calculate the magnetic perturbations along a low altitude satellite track given arbitrary distributions of continuous current density.

- We used AMPTE/CCE magnetic field data in coordination with GOES, upstream solar wind, and ground magnetometer data to understand the propagation of MHD waves in the magnetosphere in association with solar wind changes and substorm onsets.

- We provided assistance to the development of a technology demonstration MEMS magnetometer instrument for flight on the upcoming APEX rocket experiment. This will provide the first ever flight demonstration of MEMS technology for magnetometery.

- We used UARS magnetic field data in conjunction with ground magnetometer data to identify overflights by UARS at times of SI or Pi2 events. We also binned UARS magnetic field data organized by local time and the dip equator to investigate average characteristics of equatorial current system signatures.

WORK COMPLETED and RESULTS

Work completed recently is organized according to three scientific areas of research: Field-aligned currents, ULF waves and magnetospheric substorms. In addition to scientific researches we continue to explore the possibility to apply new technology to future missions. Drs. Zanetti and Anderson are taking the lead in this area. These efforts with respect to MEMS instrumentation, Iridium and COSMIC are in progress. A MEMS instrument is now ready to fly on APEX as a technology demonstration flight of opportunity. Analysis of Iridium data has shown that these data can be used for Space Weather purposes and discussions are proceeding well to establishing regular data access. Planning has just begun for obtaining science results from magnetometery on COSMIC.

Field-Aligned Currents

Drs. Potemra and Zanetti conducted joint research projects with other research institutes, including international collaborations with space science communities in Sweden and Japan. Dr. Ohtani led the effort to study the dynamics of dayside FAC systems by using coordinated Viking and DMSP measurements. Dr. Anderson contributed to several storm studies based on the UARS data. Dr. Ohtani is convening an AGU Chapman Conference on Magnetospheric Current Systems, which will be held in January 1999.

It is generally accepted that there are three large-scale FAC systems in the dayside high-latitude region, that is, the region 2 (R-2), the region 1 (R-1), and the midday region 0 (R-0) (traditionally called cusp or mantle) systems. Ref. 6 found that the R-1 and R-0 systems in the midday sector persistently exist, though with a smaller magnitude, even when magnetic activity is so low that FACs basically disappear on the night side. Ref. 6 also concluded that the response time of the dayside current system to IMF changes is a few minutes. By combining magnetic field and particle precipitation measurements above the ionosphere, Ref. 4 addressed the radial profile of plasma pressure in the magnetosphere and discussed the generation of FACs. As examined in Refs. 1 and 9, there are structures embedded in large-scale FAC systems, which are accompanied by corresponding electric field and particle flux variations. Ref. 7 examined the current-voltage (j-V) relationship for small-scale FACs associated with electron acceleration observed over an auroral surge and confirmed that Knight's formula holds for field-aligned potential differences up to 20 keV. Ref. 1 and 2 studied the development of FACs and associated Joule and particle heating during the November 1993 storm, showing that the FACs extend well equatorward of 60° during storm main phase and that the Joule heating dominates over particle heating, particularly on the dayside. Ref. 3 found that magnetic fluctuations below 100 Hz are an excellent indicator of the boundaries of large-scale FAC systems and therefore can be used for monitoring the location of auroral oval/electrojet at quasi real time. Therefore, as proposed in Ref. 5, the simple measurement of AC magnetic fluctuations by low-altitude satellites can be a practical and useful element of the space weather monitoring.

ULF Waves

Significant advances have been made in the area of magnetospheric ULF waves through multipoint and multi-instrument observations as well through collaboration with theory experts. Drs. Anderson and Erlandson led the effort concerning electromagnetic ion cyclotron (EMIC) waves observed primarily in the Pc1 band. Drs. Takahashi, Potemra, Anderson, and Ohtani worked on magnetohydrodynamic (MHD) waves in the Pc3-5 and Pi2 bands. In addition to these activities Dr. Anderson has served as Chairman of IAGA ULF Waves Working group and Dr. Takahashi as the Reporter of the same group.

Important issues associated with EMIC waves were addressed including wave occurrence statistics [12] ion heating [10] and wave propagation [14]. Ref. 14 investigated the generation mechanism and space-to-ground propagation of Pc 1 waves. Ref. 11 analyzed a ground-space (Viking) propagation time delay of a structured Pc 1 event just inside the plasmapause and concluded that the structure propagated downward. Ref. 12 used Freja data to investigate the spatial occurrence pattern of EMIC waves at higher frequencies (5-256 Hz). These waves occur primarily at auroral latitudes in the premidnight sector (1800-0100 MLT), suggesting that precipitating auroral electrons provide free energy to the waves between 1500 and 5500 km altitude.

Multipoint observations were also the main thrust in the area of MHD waves. Ref. 13 sought to observationally test the presence of cavity mode waves and their coupling to Alfvén waves on the dayside, which continues to be a major challenge. The results indicate that due to presence of multiple source mechanisms, the dayside magnetosphere is not as simple as a simulation box. Ref. 15 examined a Pc 5 event observed by coordinated ISTP satellites and ground observatories in the entire morning sector and concluded that the wave was excited by the Kelvin-Helmholtz instability at the magnetopause.

Substorms

The magnetospheric substorm is a process in which energy is stored in the magnetotail and is released explosively, causing dramatic phenomena in various regions of the magnetosphere and in the ionosphere. Therefore, changes in the tail magnetic flux and the tail current intensity, which can be inferred from the measurement of magnetic field, are most important for substorm dynamics. Dr. Ohtani has been working on near-Earth substorm processes by focusing on tail current disruption. Drs. Takahashi and Anderson examined energetic particle injection observed by AMPTE/CCE by applying a particle trace code developed by Dr. Anderson. Dr. Ohtani is serving as a co-chair of the observation working group of the NSF/GEM nightside campaign.

Ref. 21 examined characteristics of magnetic fluctuations at the local onset of dipolarization observed by the AMPTE/CCE satellite in the near-Earth (< 8.8 RE) plasma sheet by comparing magnetic fluctuations observed at the AMPTE/CCE and SCATHA satellites located close to each other, and found that the coherence length is of the order of the proton gyroradius. These findings suggest that ions play an important role in tail current disruption, and place a constraint on future modeling efforts of tail current disruption.. Ref. 20 statistically examined the time difference between local dipolarization onsets at two satellite positions and confirmed (for the first time since it was suggested 25 years ago) that dipolarization expands earthward at a velocity up to a few hundred km/s. This result may provide a useful clue to model the connection between tail current disruption and near-Earth reconnection.. Multisatellite observations are very useful for studying the spatial development of a substorm. Ref. 10 combined measurements made by 11 spacecraft suggesting the existence of multiple activation sites in the near-Earth region.

Ref. 22 provided new insight about substorm-associated energetic particle injection. One peculiar feature observed on the dayside near CCE apogee is the lack of injections at pitch angles near 90°. Numerical particle tracing indicates that drift shell splitting causes a ~3 RE spread in the radial distance of particle positions at midnight for the full range of dayside pitch angles. Thus, the pitch angle dependence of the dayside injections is explained by assuming that an injection source region had an inner edge located between the drift shells for pitch 0° and 90° pitch angles. Another puzzling feature of substorm injections is that the lower pitch angle particles are observed to arrive earlier that 90° pitch angle particles. Modeling and observations by Refs. 18 and 23 revealed quantitative agreement with drift in realistic magnetic field models and showed that the source of the dispersion is the dayside compression of the magnetospheric field. These results place us in a position to use pitch angle signatures to diagnose substorm ion injections.

IMPACT/APPLICATIONS

The wide use of magnetometers on LEO spacecraft implies that these data will be obtained from more and more space platforms. The expertise we have gained in processing and understanding the geophysical signatures in these data provides an opportunity at least in principle to assemble this constellation of data to provide the first ever global and continuous system of observations covering all local times, both hemispheres, to provide unprecedented monitoring of the magnetosphere/ionospheric system state. The increased understanding of ULF waves increases the ability to characterize the magnetospheric behavior on the basis of ground based observations. Our understanding of the nature of substorm initiation brings us closer to being able to predict the precise conditions under which these explosive events will occur. The understanding of the remote signatures of substorm injections provides a new diagnostic tool with which to study the substorm injection process which has implications for the energization of the ring current and radiation belt during geomagnetic storms.

TRANSITIONS

We are currently working on two initiatives involving spacecraft constellations, both of which use attitude magnetometers as part of their systems architecture. We are currently in legal negotiations with Iridium LLC for use of their data. In addition, we have recently been contacted and have had discussions with COSMIC regarding JHU/APL providing assistance in achieving scientific results from the attitude magnetic field systems planned for these spacecraft as well.

RELATED PROJECTS

We are working on four projects related to this effort. (1) Substorms: Using magnetic signatures from GOES and GEOTAIL spacecraft we are studying the timing and evolution of the substorm onset process. This analysis relies on work performed understanding the propagation of substorm onset signatures through the magnetosphere. This is supported under the NASA SR&T program. (2) Space Weather: The Iridium satellites carry attitude magnetometers and the understanding of field aligned current signatures and methods for processing magnetic field data from low Earth orbit derived from this project are instrumental in developing techniques to automatically process data from the Iridium constellation. This work is supported under the National Space Weather Program by NSF. (3) COSMIC: Our experience with and resources under this project for studying magnetometery from low altitude platforms has allowed us to advise the COSMIC program about how to obtain science data from the attitude magnetometers of this proposed constellation mission. Support for continued assistance to COSMIC is being sought.

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